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Distribution of terminal nerve entry points to the flexor and extensor groups of forearm muscles: an anatomical study

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The motor points of the skeletal muscles, mainly of interest to anatomists and physiologists, have recently attracted much attention from researchers in the field of functional electrical stimulation. The muscle motor point has been defined as the entry point of the motor nerve branch into the epimysium of the muscle belly. Anatomists have pointed out that many muscles in the limbs have multiple motor points. Knowledge of the location of nerve branches and terminal nerve entry points facilitates the exact insertion and the suitable selection of the number of electrodes required for each muscle for functional electrical stimulation. The present work therefore aimed to describe the number, location, and distribution of motor points in the human forearm muscles to obtain optimal hand function in many clinical situations.

Twenty three adult human cadaveric forearms were dissected. The numbers of primary nerves and motor points for each muscle were tabulated. The mean numbers and the standard deviation were calculated and grouped in tables. Data analyses were performed with the use of a statistical analysis package (SPSS 13.0). The proximal third of the muscle was the usual part of the muscle that received the motor points. Most of the forearm muscles were innervated from the lateral side and deep surface of the muscle. The information in this study may also be usefully applied in selective denervation procedures to balance muscles in spastic upper limbs.

Key words: muscle motor points, electrical stimulation

INTRODUCTION

The motor points of the skeletal muscles, mainly of interest to anatomists and physiologists, have recently attracted much attention from researchers in the field of functional electrical stimulation [17]. Functional electrical stimulation has been investigated and applied successfully to restore the motor functions of extremities paralysed because of injury or disease of the upper motor neurons, in other words spinal cord injuries or cerebrovascular disorders [12, 20, 22]. The muscle motor point has been defined as the entry point of the motor nerve branch into the epimysium of the muscle belly [15]. Anatomists have pointed out that many muscles in the limbs have multiple motor points [14]. Knowledge of the location of nerve branches and terminal nerve entry points facilitates the exact insertion and the suitable selection of the number of electrodes required for each muscle for functional electrical stimulation [21, 28]. Bottle et al. [4] mentioned that stimulation from this area resulted in a decrease in the intensity of muscle contraction. Apart from the great importance of the motor points of the

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skeletal muscles in functional electrical stimulation, the branching pattern of the ulnar nerve in the forearm is, as indicated by Marur et al. [18], of great importance in anterior transposition of the ulnar nerve for decompression after neuropathy of cubital tunnel syndrome and malformations resulting from distal end fractures of the humerus. Lim et al. [13] provided useful information for enabling the local transfer of the flexor carpi ulnaris muscle as a whole, both for resurfacing in the vicinity of the elbow and for functional tendon transfers for muscle paralysis, congenital defects and muscle defects resulting from trauma, and after resections for neoplasm and infection. The flexor carpi ulnaris branch of ulnar nerve to the pronator teres nerve was transferred by Boutros et al. [5]. The information in this study may also be usefully applied in selective denervation procedures to balance muscles in spastic upper limbs [14]. The information available on the innervation pattern of the human forearm muscles in standard anatomy texts, although adequate for routine procedures, is not detailed enough for surgical reconstruction in complex injuries of the limb and for paralytic conditions of the forearm from peripheral nerve and spinal cord injuries. The present work therefore aimed to describe the number, location, and distribution of motor points in the human forearm muscles to obtain optimal hand function in many clinical situations.

MATERIAL AND METHODS

Twenty three adult human cadaveric forearms were dissected. The limbs were placed with the elbow extended and the wrist in the neutral position. Midline volar and dorsal incisions were made from above the elbow to below the wrist. The contribution of the main nerve trunks to each forearm muscle was examined. The location and number of the primary motor nerve branching points and of the terminal nerve entry points to each muscle were investigated. The motor points were identified as being either at the proximal, middle or distal third of the muscle belly. The muscle belly was defined as the fleshy portion of the muscle. The location of the motor points to each muscle on the deep or superficial surface or the lateral or medial side of the muscle belly was also investigated. All the muscles were freed from their origin and insertion together with their primary motor branches and photographed individually at resting length.

Statistical analysis

The number of primary nerves and motor points for each muscle were tabulated. The mean number and the standard deviation were calculated and grouped in tables.

The distribution of motor points along the length of each muscle belly was noted as being either in the proximal, middle or distal third of the muscle belly. The data analyses were performed with the use of a statistical analysis package (SPSS 13.0).

RESULTS

Innervation of the forearm muscles

The minimum, maximum, mean and standard deviation for the primary nerves and their motor points for each flexor and extensor muscle are summarised in Tables 1 and 2, respectively. The median nerve and its anterior interosseus branch supplied the flexor forearm muscles except for the medial half of the flexor digitorum profundus and the flexor carpi ulnaris, which were supplied by the ulnar nerve. Most of the extensor forearm muscles were supplied by the posterior interosseus nerve, except for the brachioradialis and extensor carpi radialis longus, which were supplied by the radial nerve itself. The posterior interosseus nerve branches 0.3 ± 0.1 cm from the distal edge of the superficial head of the supinator muscle and 7.9 ± 0.6 cm from the lateral epicondyle. It forms a common stem, from which arise branches to supply the extensor forearm muscles. The lengths of the forearms ranged from 21 cm to 24.8 cm (23.2 ± 1.3).

Distribution of the motor points in each muscle belly

Flexor forearm muscles. The proximal third of the muscle was the usual part of the muscle that received the motor points except in the cases of the pronator teres and the flexor digitorum superficialis and profundus, which might receive additional branches to the middle third of the muscle. An additional small nerve branch to the distal third of the muscle was seen supplying the flexor carpi ulnaris and flexor digitorum superficialis muscles. The pronator quadratus was the only muscle of the flexor group that was supplied by the motor branches along its whole length in all the dissected specimens. In some specimens the flexor digitorum superficialis and profundus were supplied along their whole length (Table 3).

Extensor forearm muscles. Most of the extensor forearm muscles were found to have all their motor points within their proximal third. The extensor carpi radialis longus, extensor carpi radialis brevis, extensor digitorum and extensor pollicis brevis received additional motor points to their middle thirds.

Table 1. Summary of primary nerves and their motor points to the flexor forearm muscles in humans

Flexor forearm muscles	Minimum		Maximum		Mean ± SD	
	P	M	P	M	P	M
Pronator teres	2	2	2	4	2.0 ± 0.0	3.04 ± 0.7
Flexor carpi radialis	1	2	2	3	1.1 ± 0.3	2.2 ± 0.4
Palmaris longus	1	2	1	2	1.0 ± 0.0	1.7 ± 0.5
Flexor carpi ulnaris	2	2	3	3	2.6 ± 0.5	2.7 ± 0.5
Flexor digitorum superficialis	2	3	8	9	4.2 ± 2.6	4.8 ± 2.8
Flexor digitorum profundus	3	6	6	8	4.5 ± 1.3	7.1 ± 0.8
Flexor pollicis longus	1	3	1	4	1.0 ± 0.0	3.6 ± 0.5
Pronator quadratus	3	3	4	4	3.6 ± 0.5	3.6 ± 0.5

P — primary nerve; M — motor points, SD — standard deviation

Table 2. Summary of primary nerves and their motor points to the extensor forearm muscles in humans

Extensor forearm muscles	Minimum		Maximum		Mean ± SD	
	P	M	P	M	P	M
Brachioradialis	2	2	2	4	2.0 ± 0.0	3.1 ± 0.8
Extensor carpi radialis longus	1	1	1	2	1.0 ± 0.0	1.7 ± 0.5
Extensor carpi radialis brevis	1	2	2	5	1.2 ± 0.4	3.7 ± 1.3
Extensor digitorum	1	2	3	5	1.7 ± 1.0	3.4 ± 1.3
Extensor digiti minimi	1	2	1	3	1.0 ± 0.0	2.6 ± 0.5
Extensor carpi ulnaris	1	2	2	3	1.2 ± 0.4	2.7 ± 0.5
Abductor pollicis longus	1	2	2	4	1.3 ± 0.4	2.5 ± 0.7
Extensor pollicis brevis	1	2	3	4	2.0 ± 1.0	3.3 ± 0.7
Extensor pollicis longus	1	1	1	3	1.0 ± 0.0	2.2 ± 0.5
Extensor indicis	1	2	2	3	1.5 ± 0.5	2.5 ± 0.5
Supinator	1	2	1	3	1.0 ± 0.0	2.4 ± 0.5

P — primary nerve; M — motor points, SD — standard deviation

Table 3. Summary of the distribution of motor points of the flexor forearm muscles in humans

Name of muscle	Proximal third		Proximal and middle thirds		Along its whole length		Distal third	
	No.	%	No.	%	No.	%	No.	%
Pronator teres	—		23	100	—		—	
Flexor carpi radialis	23	100	—		—		—	
Palmaris longus	23	100	—		—		—	
Flexor carpi ulnaris	23	100	—		—		17	73.9
Flexor digitorum superficialis	—		4	17.4	11	47.8	8	34.8
Flexor digitorum profundus	23	100	14	60.9	9	39.1	—	
	From ulnar nerve		From anterior interosseus		From anterior interosseus			
Flexor pollicis longus	23	100	—		—		—	
Pronator quadratus	—		—		23	100	—	

Table 4. Summary of the distribution of motor points of the extensor forearm muscles in humans

Name of muscle	Proximal third		Proximal and middle thirds		Along its whole length		Middle third	
	No.	%	No.	%	No.	%	No.	%
Brachioradialis	23	100	—		—		—	
Extensor carpi radialis longus	—		15	65.2	—		8	34.8
Extensor carpi radialis brevis	18	78.3	5	21.8	—		—	
Extensor digitorum	15	65.2	8	34.8	—		—	
Extensor digiti minimi	23	100	—		—		—	
Extensor carpi ulnaris	23	100	—		—		—	
Abductor pollicis longus	23	100	—		—		—	
Extensor pollicis brevis	12	52.2	11	47.8	—		—	
Extensor pollicis longus	23	100	—		—		—	
Extensor indicis	—		—		—		23	100
Supinator	23	100	—		—		—	

The motor points for the extensor indicis muscle was seen to enter its middle third only (Table 4).

Location of the motor points in the forearm muscles

Most of the forearm muscles were innervated from the lateral side and deep surface of the muscle except for the flexor digitorum profundus, flexor pollicis longus, abductor pollicis longus and the supinator muscles, which were supplied from their superficial surfaces. The motor points were located along the midline and the deep surface of the pronator quadratus muscle (Fig. 1–27).

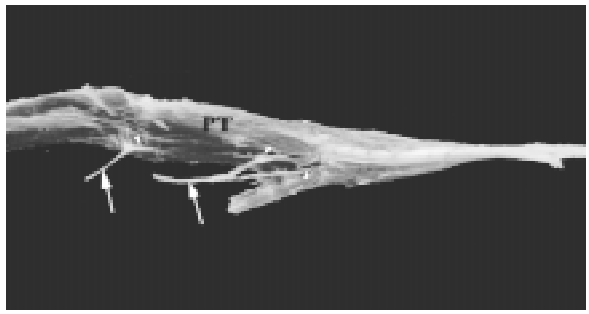

Figure 2. A magnified photograph of the previous pronator teres muscle (PT) showing the two primary nerves (↑) with their three motor points (‹) entering the proximal and middle thirds of the muscle from its lateral aspect and deep surface.

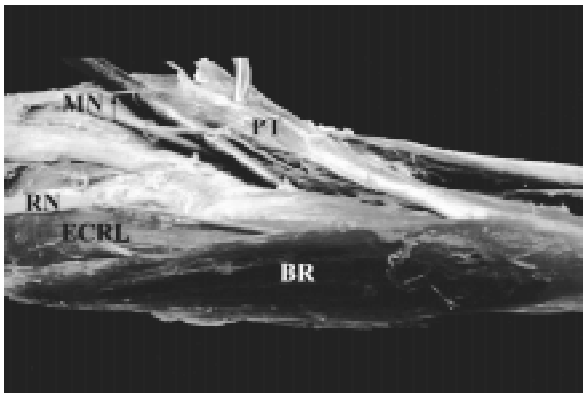

Figure 1. A photograph of a dissected right forearm showing two primary motor nerves (↑) to the pronator teres muscle (PT) arising from the median nerve (MN) before it enters between the two heads of the muscle. RN — radial nerve; ECRL — extensor carpi radialis longus; BR — brachioradialis.

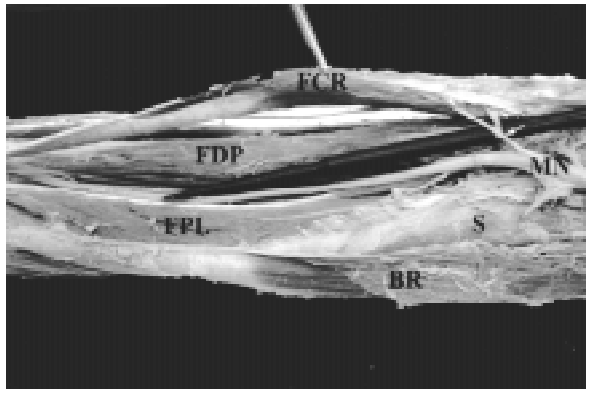

Figure 3. A photograph of a dissected left forearm showing one primary motor nerve (↑) from the median nerve (MN) to the flexor carpi radialis muscle (FCR) supplying its lateral aspect and deep surface, with two motor points (‹) entering the proximal third of the muscle. FDP — flexor digitorum profundus muscle; FPL — flexor pollicis longus muscle; BR — brachioradialis muscle; S— supinator muscle.

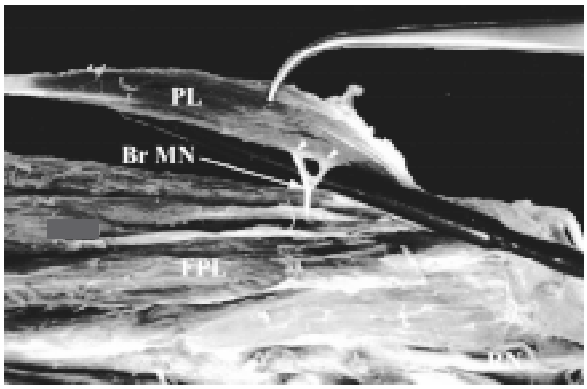

Figure 4. A photograph of a dissected left forearm showing one primary branch from the median nerve (Br MN) with its two motor points (‹) supplying the proximal third of the palmaris longus (PL) muscle. RN — radial nerve; FDP — flexor digitorum profundus muscle; FPL — flexor pollicis longus muscle.

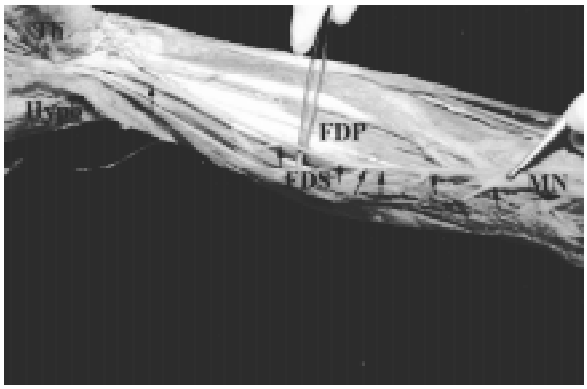

Figure 7. A photograph of a dissected right forearm showing eight primary nerves (↑) from the median nerve (MN) supplying the flexor digitorum superficialis muscle (FDS) from its lateral aspect and deep surface. FDP — flexor digitorum profundus; Th — thenar muscles; Hypo — hypothenar muscles.

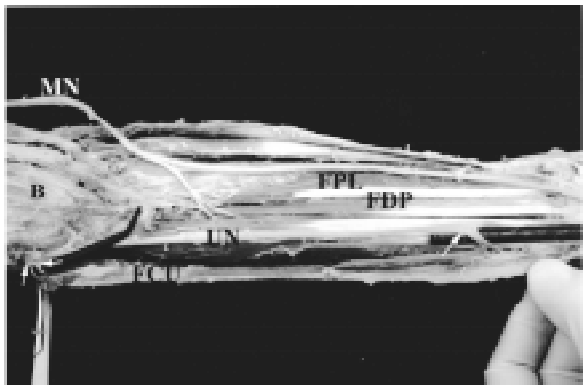

Figure 5. A photograph of a dissected left forearm showing three primary nerves (↑) arising from the ulnar nerve (UN) to the proximal and distal thirds of the flexor carpi ulnaris muscle (FCU) supplying its lateral aspect and deep surface. FDP — flexor digitorum profundus muscle; FPL — flexor pollicis longus muscle; B — brachialis muscle; MN — median nerve.

Figure 8. A photograph of the previous flexor digitorum superficials muscle (FDS) showing nine motor points (‹) supplying the muscle. MN — median nerve.

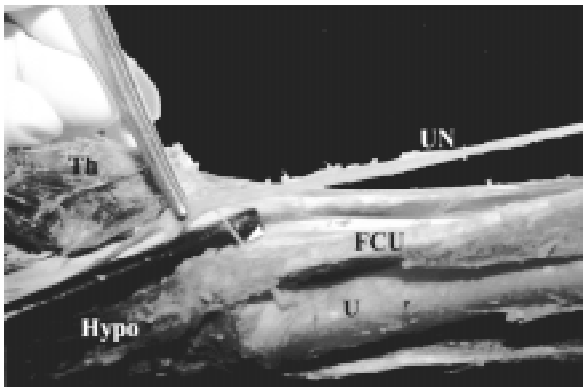

Figure 6. A photograph of the previous flexor carpi ulnaris muscle (FCU) showing the motor point to the distal third of the muscle (‹). Th — thenar muscles; Hypo — hypothenar muscles; UN — ulnar nerve; U — ulna.

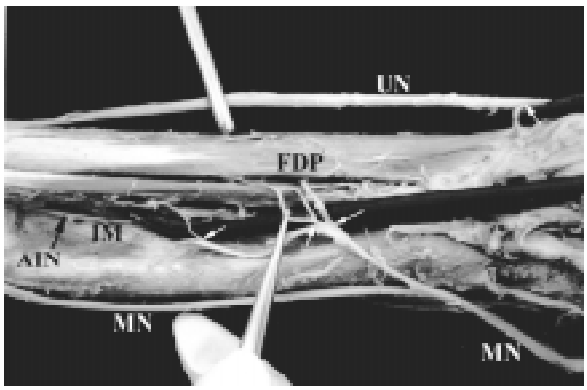

Figure 9. A Photograph of a dissected left forearm showing three primary nerves (↑) to the flexor digitorum profundus (FDP) arising from the anterior interosseus nerve (AIN) and one from the ulnar nerve (UN) supplying the proximal and middle thirds of the muscle. IM — interosseus membrane; MN — median nerve.

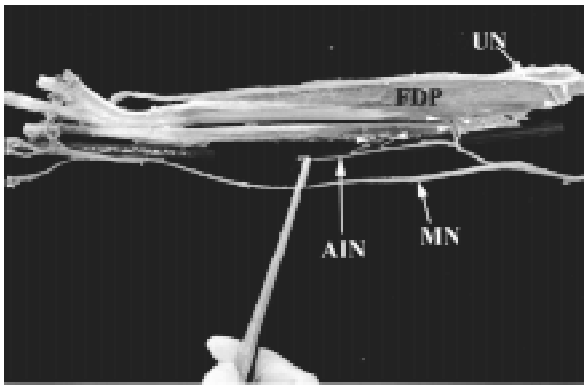

Figure 10. A photograph of the previous flexor digitorum profundus muscle (FDP) showing five motor points (‹) from the anterior interosseus nerve (AIN) and two points from the ulnar nerve (UN) supplying the superficial surface of the muscle. MN — median nerve.

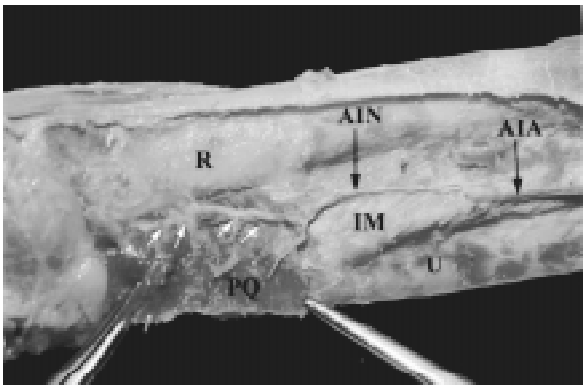

Figure 13. A photograph of a dissected right forearm showing four primary nerves (↑) from the anterior interosseus (AIN) to the pronator quadratus muscle (PQ) along its length. R — radius; U — ulna; IM: — interosseus membrane; AIA — anterior interosseus artery.

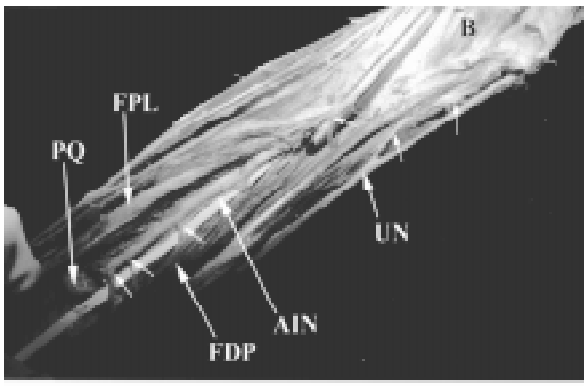

Figure 11. A photograph of a dissected right forearm showing four primary nerves (↑) from the anterior interosseus nerve (AIN) and two from the ulnar nerve (UN) supplying the flexor digitorum profundus muscle (FDP). PQ — pronator quadratus; FPL — flexor pollicis longus; B — brachialis muscle.

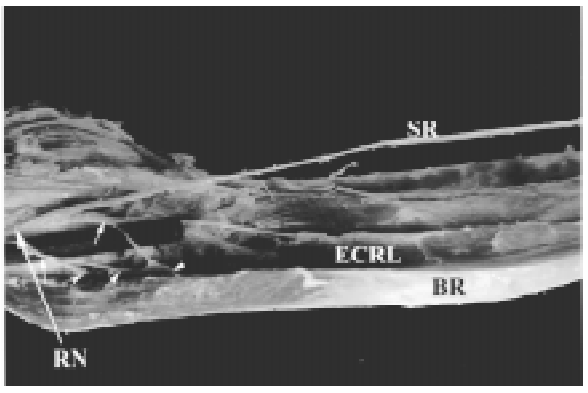

Figure 14. A photograph of a dissected right forearm showing two primary nerves (↑) from the radial nerve (RN) with three motor points (‹) supplying the proximal third of the brachioradialis muscle (BR). ECRL — extensor carpi radialis longus; SR — superficial radial.

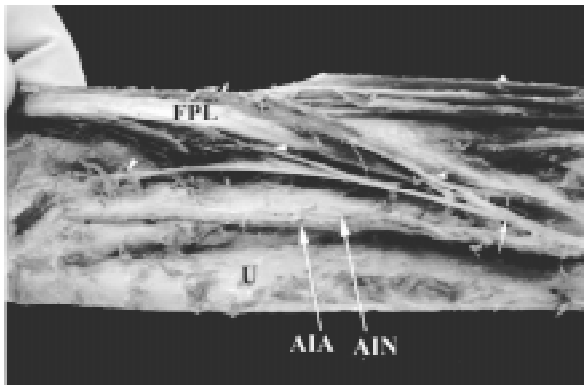

Figure 12. A photograph of a dissected right forearm showing one primary nerve (↑) with three motor points (‹) to the proximal third of the flexor pollicis longus muscle (FPL) arising from the anterior interosseus nerve (AIN). The motor points are entering the superficial and medial aspect of the muscle. AIA — anterior interosseus artery; U — ulna.

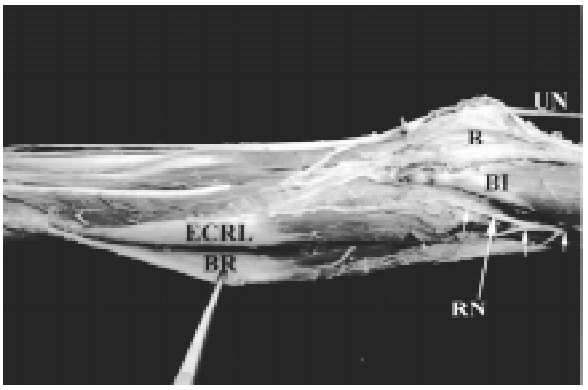

Figure 15. A photograph of a dissected left forearm showing two primary nerves (↑) to the proximal third of brachioradialis muscle (BR) and one to the middle third of extensor carpi radialis longus muscle (ECRL) arising from the radial nerve (RN). B — brachialis muscle; BI — biceps brachii muscle; UN — ulnar nerve.

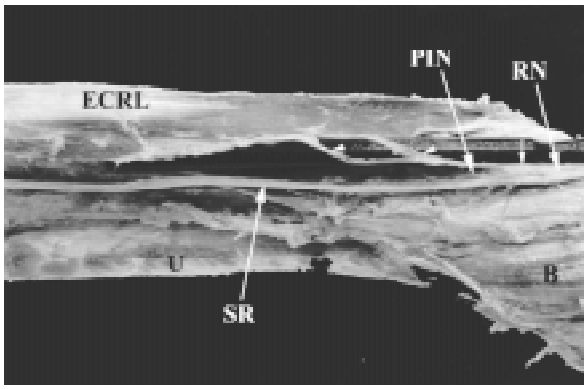

Figure 16. A photograph of a dissected right forearm showing one primary nerve (↑) with two motor points (‹) supplying the proximal and middle thirds of the extensor carpi radialis longus muscle (ECRL) arising from radial nerve (RN). U — ulna; B — brachialis muscle; SR — superficial radial; PIN — posterior interosseus nerve.

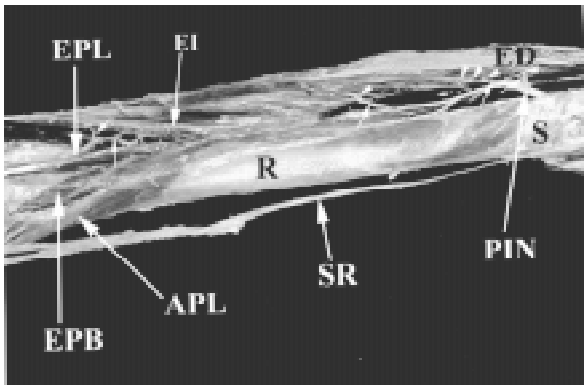

Figure 19. A photograph of a dissected right forearm showing three primary nerves (↑) with five motor points (‹) to the proximal and middle thirds of the extensor digitorum muscle (ED) arising from posterior interosseus nerve (PIN). The middle third of the extensor indicis (EI) is seen supplied by two primary nerves (↑) with three motor points (‹). S — supinator muscle; R — radius; SR — superficial radial; APL — abductor pollicis longus muscle; EPB — extensor pollicis brevis muscle; EPL — extensor pollicis longus muscle.

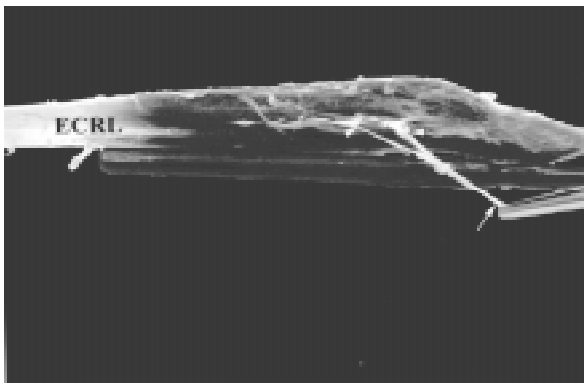

Figure 17. A photograph of the previous extensor carpi radialis longus muscle (ECRL) showing one primary nerve (↑) with two motor points (‹) supplying the deep surface of the muscle.

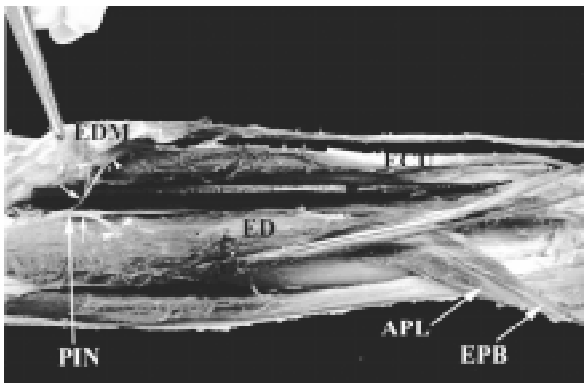

Figure 20. A photograph of a dissected left forearm showing one primary nerve (↑) with two motor points (‹) to the proximal third of each of the extensor digitorum (ED) and extensor digiti minimi (EDM) arising from the posterior interosseus nerve (PIN). ECU — extensor carpi ulnaris muscle; APL — abductor pollicis longus muscle; EPB — extensor pollicis brevis muscle.

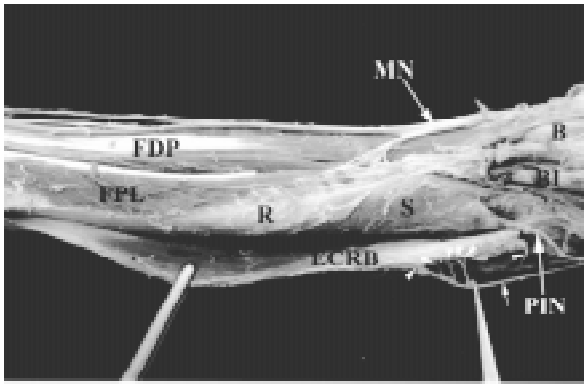

Figure 18. A photograph of a dissected left forearm showing one primary nerve (↑) with five motor points (‹) supplying the proximal third of the extensor carpi radialis brevis (ECRB) arising from the posterior interosseus nerve (PIN). S — supinator muscle; R — radius; FPL — flexor pollicis longus; FDP — flexor digitorum profundus; MN — median nerve; BI — biceps brachii muscle; B — brachialis muscle.

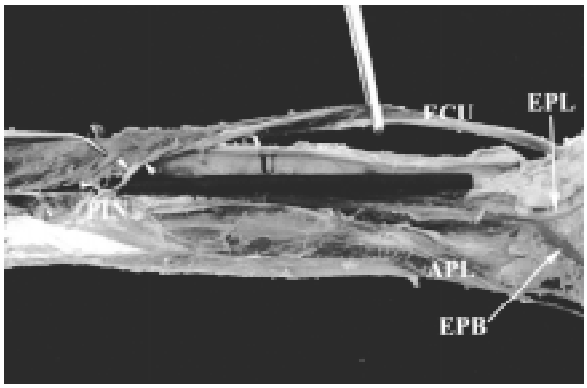

Figure 21. A photograph of a dissected left forearm showing one primary nerve with three motor points (‹) supplying the extensor carpi ulnaris muscle (ECU) from the posterior interosseus nerve (PIN). U — ulna; APL — abductor pollicis longus muscle; EPB — extensor pollicis brevis muscle; EPL — extensor pollicis longus muscle.

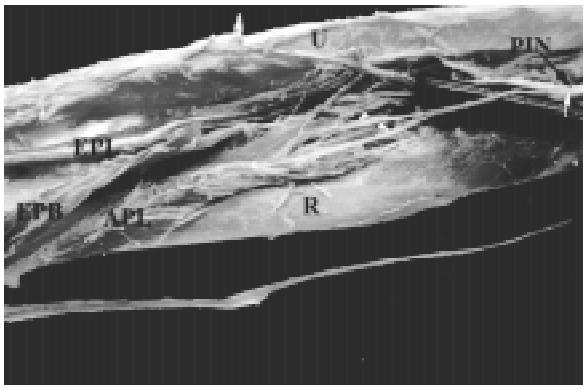

Figure 22. A photograph of a dissected right forearm showing one primary nerve (↑) with two motor points (‹) to the superficial surface of the abductor pollicis longus muscle (APL) arising from the posterior interosseus nerve (PIN). U — ulna; R — radius; EPB — extensor pollicis brevis muscle; EPL — extensor pollicis longus muscle.

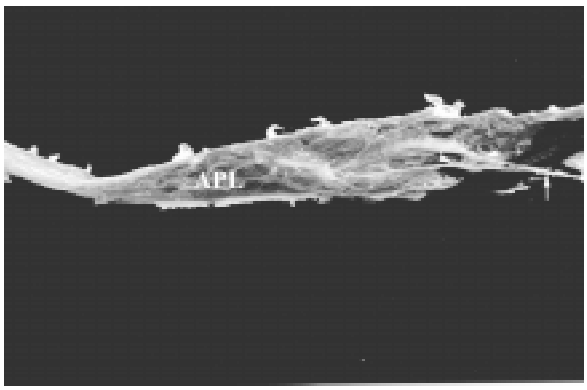

Figure 23. A magnified photograph of the previous abductor pollicis longus muscle (APL) showing one primary nerve (↑) with two motor points (‹) supplying the superficial surface of the proximal third of the muscle.

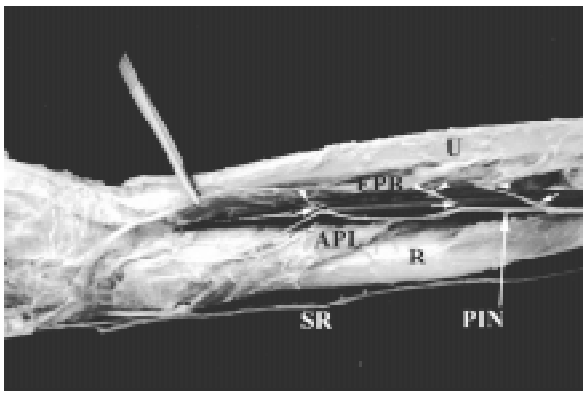

Figure 24. A photograph of a dissected right forearm showing three primary nerves (↑) and four motor points (‹) supplying the upper two thirds of the extensor pollicis brevis (EPB). These arise from the posterior interosseus nerve (PIN). U — ulna; R — radius; SR — superficial radial nerve; APL — abductor pollicis longus muscle.

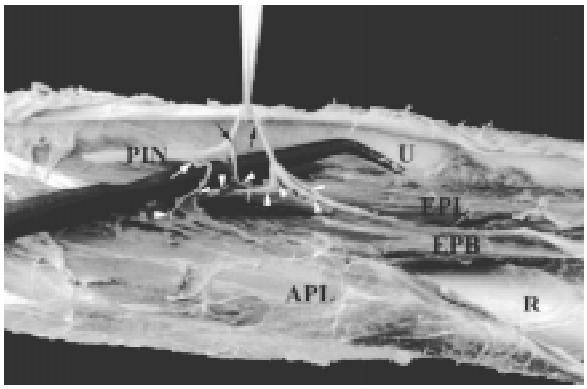

Figure 25. A photograph of a dissected left forearm showing one primary nerve (↑) with two motor points (‹) supplying the proximal third of each of the extensor pollicis longus muscle (EPL) and the abductor pollicis longus muscle (APL), arising from the posterior interosseus nerve (PIN). The extensor pollicis brevis muscle (EPB) was supplied by one primary nerve with four motor points. U — ulna; R — radius.

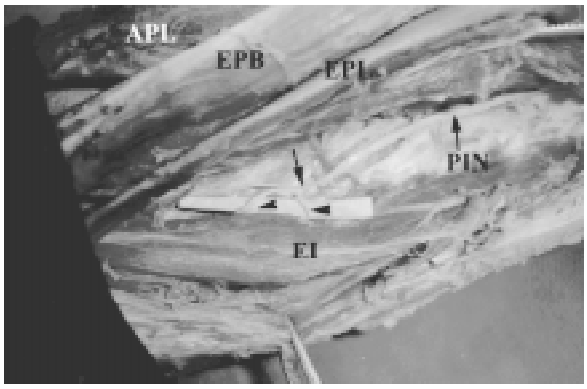

Figure 26. A photograph of a dissected left lower forearm showing one primary nerve (↑) with two motor points (‹) to the middle third of the extensor indicis (EI) arising from the posterior interosseus nerve (PIN). APL— abductor pollicis longus muscle; EPB — extensor pollicis brevis muscle; EPL — extensor pollicis longus muscle.

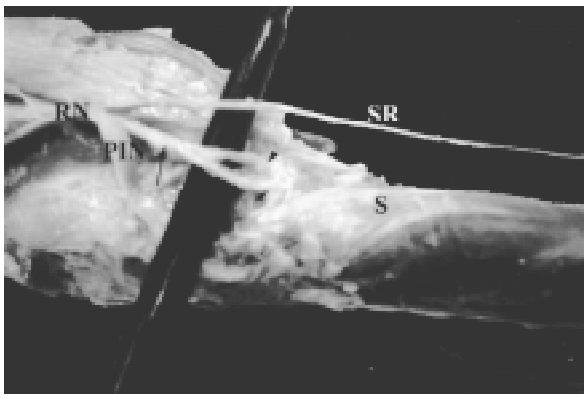

Figure 27. A photograph of a dissected upper left forearm showing one primary nerve (↑) with two motor points (‹) to the supinator muscle (S). SR — superficial nerve; RN — radial nerve; PIN — posterior interosseus nerve.

DISCUSSION

The motor point, an important anatomical spot on the muscle, has been used clinically in many situations, as described above. Stimulation through electrodes placed near or at the motor points of a muscle give maximum contraction for this muscle [21].

The innervations by the median, ulnar and radial nerves for the forearm muscles were studied. The median nerve and its anterior interosseus branch supplied the flexor forearm muscles except for the medial half of the flexor digitorum profundus and flexor carpi ulnaris, which were supplied by the ulnar nerve. Most of the extensor forearm muscles were supplied by the posterior interosseus nerve except for the brachioradialis and extensor carpi radialis longus, which were supplied by the radial nerve itself. Similar results were described by Sarikcioglu et al. [23] and Boles et al. [3].

The innervations of the flexor forearm muscles were investigated and it was observed that the pronator teres muscle was supplied by two primary nerves, a finding similar to that of Chantelot et al. [7], who observed that there were two branches, superior and inferior, for the pronator teres muscle, a common trunk for the flexor carpi radialis and palmaris longus muscles and a branch for the flexor digitorum superficialis muscle. These were in agreement with our research results except for the flexor digitorum superficialis muscle, which was seen to be supplied by 2–8 primary nerves. Similar results for the palmaris longus muscle were also observed by Kawashima et al. [11] and for the flexor carpi radialis muscle by Hua et al. [10] and Segal et al. [26], who mentioned that the flexor carpi radialis was supplied by one primary nerve. In this research the flexor carpi radialis was supplied by one branch in most cases, with only 13% of dissected muscles supplied by two branches.

The flexor digitorum profundus muscle was seen to have a dual nerve supply. This was in agreement with Bhadra et al. [2], who reported that the flexor digitorum profundus muscle had a dual nerve supply and that the entry points of the ulnar and anterior interosseus nerve branches were at 15% and 30% of the forearm length respectively, distal to the medial epicondyle. Previous anatomical studies have shown that the macaque flexor digitorum profundus receives four primary nerve branches, each innervating a separate region of the muscle belly [24]. In humans Marur et al. [18] found that the flexor digitorum profundus received a single branch from the ulnar nerve in all cases except in four out of 37 dissected specimens, all of which had two branches. Segal et al. [25] mentioned that two muscle nerves innervate the flexor digitorum profundus, with branches innervating the medial and lateral regions of the muscle. Up to eight architectural partitions were found in a medial-to-lateral direction. In our research the muscle was supplied from 3 to 6 primary nerves.

The flexor carpi ulnaris was supplied by 2 to 3 primary nerves in this work. Marur et al. [18] observed that one or two branches were usually associated with the innervation of the flexor carpi ulnaris. However, in two cases three branches and in one case four branches were observed to the flexor carpi ulnaris out of the 37 dissected specimens. Segal et al. [25] and Lim et al. [13] observed that the nerve to the flexor carpi ulnaris muscle innervated two architectural partitions within the muscle. This study confirmed the great variability of the branches of the median nerve at the elbow and the importance of identifying them in surgical procedures for transposition of the medial epicondyle.

Knowledge of radial nerve motor branch anatomy is important when performing surgery in its vicinity, nerve repair and nerve blocks for understanding the rate and order of recovery of muscle function after injury [1, 27]. In this research the posterior interosseus nerve was seen to branch 0.3 ± 0.1 cm from the distal edge of the superficial head of the supinator muscle and 7.9 ± 0.6 cm from the lateral epicondyle. It formed a common stem, from which branches arose to supply the extensor forearm muscles. The lengths of the forearms ranged from 21 cm to 24.8 cm (23.2 ± 1.3). Very similar results were obtained by Elgafy et al. [8, 9] who mentioned that the posterior interosseus nerve branched at 0.43 ± 0.52 cm from the distal edge of the superficial head of the supinator and 8 ± 1.6 cm from the lateral epicondyle. In this research the extensor carpi radialis longus muscle was supplied by 1 to 2 motor points and the extensor carpi radialis brevis muscle was also innervated by 1 to 2 primary nerves. These results were in agreement with Segal et al. [26] and Melling et al. [19] respectively. Branovacki et al. [6] observed that the branch to the extensor carpi radialis brevis muscle arose from the posterior interosseus nerve in 45%, from the superficial sensory in 25% and at the bifurcation in 30% of specimens. In contrast, in our work the muscle was seen to be innervated in all specimens by the posterior interosseus nerve. Abrams et al. [1] mentioned that the mean number of muscular branches ranged from 1.1 in the extensor indicis to 4.6 in the extensor

digitorum. In our work it was found that the mean number of motor points was 3.4 ± 1.3 in the extensor digitorum and 2.5 ± 0.5 in the extensor indicis muscles. The lowest mean number of motor points in our work was 1.7 ± 0.5 for the extensor carpi radialis longus muscle. The extensor carpi ulnaris muscle was seen to be supplied by 1 to 2 primary nerves. Segal et al. [25] stated that the extensor carpi ulnaris muscle had a variable number of primary nerve branches. For the supinator muscle Branovacki et al. [6] mentioned that the muscle had an average of 2.3 branches from the posterior interosseus nerve. In our research the average number of motor points to the muscle was also 2.4 ± 0.5.

In this research the distribution of motor points to the forearm muscles showed that most of them were supplied in the proximal third except for the pronator teres, flexor carpi ulnaris, flexor digitorum superficialis and profundus, pronator quadratus, extensor carpi radialis longus and brevis, extensor digitorum, extensor pollicis brevis and extensor indicis muscles, which were supplied in the proximal third in addition to the distal third or along the whole length. This has also been observed by many other researchers. Liu et al. [16] mentioned that in 13 out of 19 forearm muscles the statistical median location of the terminal nerve entry points was within the proximal third in 9 forearm muscles and within the middle third of the forearm in 8 forearm muscles. In the remaining two muscles it was located proximal to the elbow or in the distal third of the forearm respectively. Segal et al. [26] and Hua et al. [10] observed that the flexor carpi radialis was supplied proximally. Segal et al. [26] mentioned that the extensor carpi radialis longus was supplied by two primary nerves, one to the proximal and one to the distal third of the muscle.

The motor points were seen to be located mostly on the lateral surface and deep surface of the muscle except for the flexor digitorum profundus, flexor pollicis longus, supinator and abductor pollicis longus muscles, which were supplied from their superficial surfaces. In agreement with our work, Yoshino and Horiguchi [29] found that the abductor pollicis longus muscle was supplied from its dorsal surface. However, this observation showed the great error in the application of surface or even percutaneous electrodes. The importance of open surgery and the precise application of electrodes by suturing them over the motor points becomes clear [21].

These results seem to support the concept that each human subject has an individual use of muscles for elbow movement. Further studies for the size and distribution of the neuromuscular compartments in each muscle belly and the type and distribution of muscle fibres in each compartment may also be needed to obtain reasonable neuromuscular stimulating patterns of the elbow movements for functional electrical stimulation.

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